Time resolved imaging of magnetic nanostructures with magnetic transmission soft X-ray microscopy

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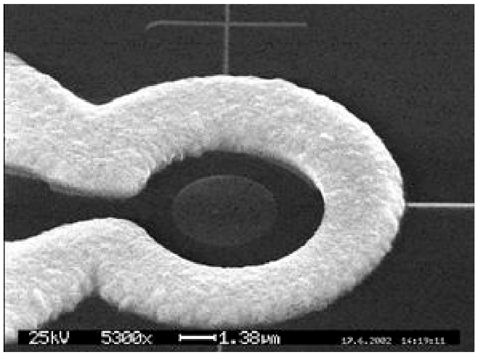
INTRODUCTION

A basic understanding of magnetism in reduced dimensions is of increasing importance for fundamental and applied reasons. Since future technological magnetic devices are designed to be as small as on a submicrometer length scale to achieve high storage density and integration they also have to be as fast as on a psec time scale to account for high speed data recording. Characteristic length scales are dictated by competing interactions, such as exchange, anisotropy and dipolar constants yielding values in the nanometer regime. Correspondingly, time scales for fast magnetization reversal mechanisms are dominated by precessional motions in the GHz range, i.e. in the sub-nsec time domain. Hence, space and time resolved magnetization studies with ultimate spatial and temporal resolution are of utmost interest and focus of a huge variety of studies and current methodical developments. So far, time resolved scanning Kerr microscopy to image the precessional motion of the magnetization vector in a magnetic microstructure has proven a 10-ps temporal resolution, however, the lateral resolution is limited by the wavelength of optical microscopies to the submicrometer range which does not match the size of nanopatterned elements, that are already discussed as potential candidates in nanomagnetism applications. Furthermore, since the functionality of advanced materials is strongly influenced by the elemental composition such as coupled multilayered systems, chemical sensitivity is needed to unravel the contribution of each layer.

EXPERIMENT

Magnetic soft X-ray transmission microscopy (MTXM), combining a (currently) 25nm lateral resolution given by Fresnel zone plate optics with X-ray magnetic circular dichroism as magnetic contrast, is a powerful technique to study static magnetic domain structures [1]. However, if the inherent time structure of the synchrotron radiation is also taking into account, this opens the possibility to address the dynamical aspects of the local magnetization, too [2]. At the ALS where the presented data have been taken the two-bunch mode of operation performs a time structure with two electron bunches separated in time by 328ns circulating in the ring with each pulse having a length of 70ps. We have set up a pump-and-probe measurement, where the pump is a short magnetic field pulse with a rise time of 100ps generated by a short electronic current into a microcoil and the probe is the X-ray flash of the synchrotron which is delayed with respect to the pump pulse up to several ns in steps of several ps to study the temporal evolution of the magnetization after the exciting pulse. A stroboscopic illumination triggered by the orbital clock of the synchrotron is performed since a single shot does not provide enough X-ray photons to generate a single image. The typical accumulation time per single image was about 3-5sec and about 500 images were summed up for each data point. To separate the small signals from the background images with the pulse applied in forward (Γ^+) and backward (Γ^-) direction were recorded to give a normalized signal $(\Gamma^+ - \Gamma^-)/(\Gamma^+ + \Gamma^-)$.



The samples were single ferromagnetic permalloy PY ($Ni_{80}Fe_{20}$) 4x4μm^2 squared and 2μm diameter circular (see Fig. 1) elements with each a thickness of 50nm. They were patterned by e-beam lithography onto a 100nm thin Si_3N_4 membrane which has a transmission of 80% around 700eV.

Figure 1. TEM graph of the circular PY dot and the surrounding microcoil prepared by lithography onto a Si_3N_4 membrane.

The images were recorded at the Fe L_3 absorption edge at 706eV, where the dichroic contrast is largest. The microcoil was prepared on the same membrane surrounding the samples with an inner diameter of 6μm and generating a magnetic field of about 100kA/m pointing perpendicular to the surface of the element. Thus a torque is exerted to the static in-plane magnetization, which starts a precessional motion with a time varying component of the magnetization out of the plane (z-component). Since the magnetic contrast is given by the projection of the magnetization on the photon propagation direction, the sample was placed into the beam with its surface normal oriented parallel to the beam and hence the static in-plane magnetization with a much larger magnetic contrast does not show up in the images.

RESULTS

The temporal evolution of the magnetization in the circular dot is shown in Fig. 2, where the delay between the pump and the probe was varied between Δt=180ps and up to Δt=1380ps after the excitation pulse. At a delay time of Δt=180ps (Fig. 2a) the shape of the dot is clearly silhouetted as a dark pattern against the region of the membrane surrounding it. This can be interpreted by the fact that the magnetization is no longer in the plane (as for the static case) but has acquired a z-component out-of-the-plane.

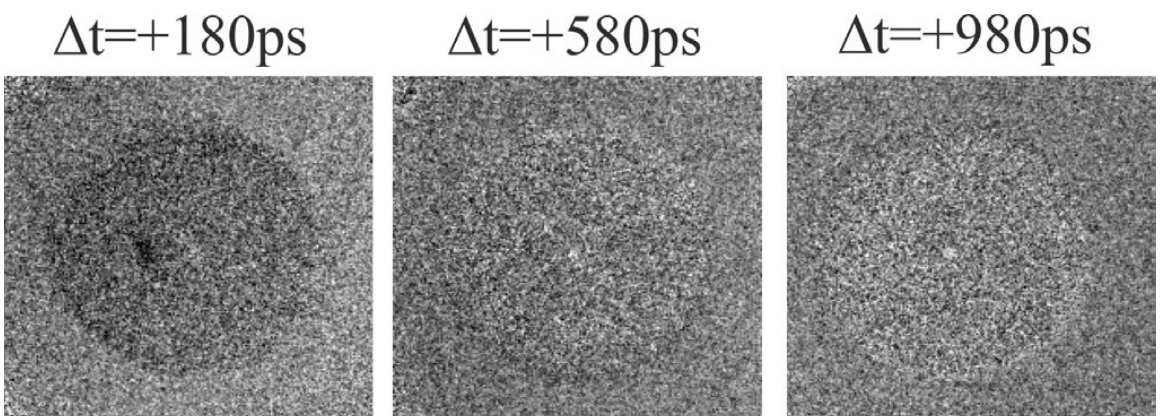


Figure 2. Temporal evolution of the magnetization´s z-component in a 50nm thin PY dot with a diameter of 2μm.

While at Δt=580ps the dot seems to fade away in the background, at Δt=980ps the magnetization of the dot points into the white direction, i.e. the z-component has reversed thereby passing the plane of the sample in between. A precession frequency of about 1GHz is consistent with these findings. Interestingly, in the center of the dot, where the static configuration exhibits the prominent vortex, the contrast seems to exhibit a white spot, which seems not to follow that precessional motion rather than keeping its orientation. However, taking into account the extension of the vortex to less than 10nm, this structure is more probable a smearing out of the vortex due to the non-perfect parallel alignment of the vortex and the applied field pulse direction.

A prominent feature of spin dynamics that has been found in the 4x4μm^2 squared element is shown in Fig. 3 (left). At a delay of 980 ps a pronounced contrast shows up along the domain walls of the static four domain Landau pattern, i.e. the precession frequency is locally different there from the adjacent closure domain regions. Micromagnetic simulations based on the Landau-Lifshitz equation are consistent with these findings (right panel).

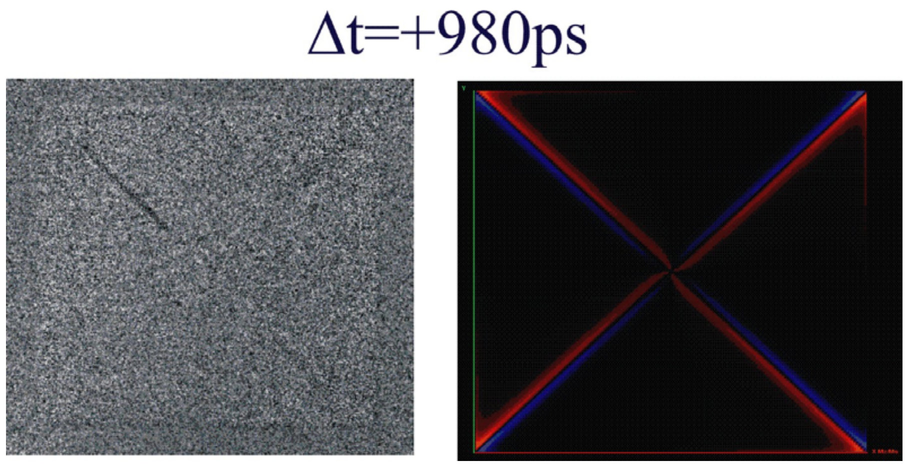


Figure 3. Left: Z-component of the magnetization in a 50nm thin PY 4x4μm^2 squared element at a delay of 980ps in comparison with simulations (right).

OUTLOOK

The inherent element-specificity will allow to study in detail the temporal evolution of the switching in individual layers in a mulicomponent magnetic nanoelement on a sub-psec time, which will provide crucial information in the development of ultrafast switching mechanisms in small magnetic structures.

ACKNOWLEDGMENTS

Support by the German National Science Foundation (DFG) under the contract FI 542/3-1,2 is highly appreciated.

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